DUAL PATH EGR SYSTEM AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of the filing of U.S. Provisional Patent Application Serial No. 60/404,955, entitled "Dual EGR Concept", filed on August 21, 2002, and the specification thereof is incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention (Technical Field):

The present invention relates to the field of internal combustion engine exhaust gas recirculation (EGR) for emissions improvement and increased operating efficiency, including increased fuel economy. More particularly, the invention provides a system and method for dual path EGR, utilizing a high pressure EGR loop, primarily for use under mid and high load engine conditions, and a low pressure EGR loop, combining turbocharger compressed exhaust gas and fresh air, primarily for use under low load engine conditions.

Description of Related Art:

EGR is a known method for reducing NOx emissions in internal combustion engines, particularly diesel engines. For effective use, an EGR system must be matched to the engine load setting and environmental conditions. High pressure loop EGR, providing a loop from the exhaust manifold of the engine to the intake manifold, optionally with an EGR cooler, works well for high power or load settings and modest EGR rates. However, at low load settings the comparatively high EGR rates result in undesirably high back pressures, resulting in a significant fuel consumption penalty.

Low pressure loop EGR typically takes exhaust gas from the exhaust, downstream of particulate traps and other emissions control devices, and injects the exhaust gas into the compressor, delivering compressed exhaust gas, typically mixed with fresh air, to the intake

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manifold of the engine. Low pressure loop EGR works well at low power or load settings. At high EGR rates low pressure loop EGR typically incurs some operational penalties, in that the balance of EGR to fresh air is such as to not provide optimal emissions control. However, at high power or load settings low pressure loop EGR incurs a very large fuel penalty, due to the need for flow ranges outside the capabilities of turbine-driven compressors, a poor turbine-to-compressor flow match and excessive heat loads.

It is also known that environmental conditions can affect the operation and efficiency of EGR systems. Specifically, in cold weather condensation is a significant issue with EGR systems, particularly high pressure loop EGR. Condensation in cold weather, typically caused by operation of the EGR cooler, results in introduction of water into the intake manifold of the engine, causing production of acids, including sulfuric and nitric acids, soot formation, and the like, all of which degrade engine life and performance.

It is known to introduce only fresh air to the inlet of an engine, typically air compressed by use of a turbine compressor. However, with use of fresh air only the benefits, including the emission control benefits, resulting from use of EGR are lost. In some systems, high pressure loop EGR is employed in combination with compressed fresh air. However, these systems still result in undesirable emission levels at low power or load settings, and are susceptible to decreased efficiency and fuel consumption penalties.

It is, therefore, desirable to provide an EGR system, and methods for such systems, which provide optimal fuel and emissions controls over a wide range of power or load settings. In many applications, including diesel engines for vehicles, the power or load setting varies over a wide range, from very low loads while the vehicle is at idle to very high loads while the vehicle is accelerating or climbing an incline. In such applications a wide range of environmental operating conditions are typically encountered, with ambient air temperatures ranging from well below 0° C to over 40° C. It is further desirable to provide an EGR system, and methods for such systems, which provide the benefits associated with high pressure EGR loop systems, without incurring the penalties associated with such systems, and which further provide the benefits associated with low pressure EGR loop systems, again without incurring the penalties associated with such systems.

BRIEF SUMMARY OF THE INVENTION

The invention provides an internal combustion engine system with a dual path EGR system, the dual path EGR including a high pressure EGR loop and a low pressure EGR loop, means for switching between the two loops, and preferably means for controlling based on one or more operating parameters of the internal combustion engine system. The system includes an engine with an exhaust manifold with an exhaust outlet and an intake manifold with an air inlet. An engine exhaust conduit is in fluidic connection with the exhaust outlet and the inlet of a first control valve with one inlet and two outlets. The high pressure EGR loop, optionally including an EGR cooler, is in fluidic connection between a first outlet of the first control valve and the air inlet of the intake manifold. The system further includes a turbocharger, preferably a variable geometry turbocharger, with an exhaust gas turbine with an input in fluidic connection with a second outlet of the first control valve and with an output, the turbocharger further having a compressor with an input and an output. An emissions controller with an input and output is provided, the input of the emissions controller being in fluidic connection with the output of the exhaust gas turbine. A low pressure EGR supply conduit is in fluidic connection with the output of the emissions controller and a fresh air inlet in fluidic connection with the input of the compressor, with a second control valve disposed along the low pressure EGR supply conduit. An intake manifold conduit, optionally with an air cooler, is in fluidic connection between the output of the compressor and the air inlet of the intake manifold. The engine system optionally and preferably includes a control, the control operating the first control valve and the second control valve to determine whether exhaust gas will enter the air inlet of the intake manifold by means of the high pressure EGR loop or by means of the intake manifold conduit, or both.

In another embodiment, the invention provides a dual loop EGR system adapted for use with an internal combustion engine, the engine having an exhaust manifold including an exhaust outlet and an intake manifold including an air inlet. In the dual loop EGR system there is provided a high pressure EGR loop in fluidic connection with the exhaust outlet of the exhaust manifold and the air inlet of the intake manifold, a turbocharger, in a preferred

embodiment a variable geometry turbocharger, including an exhaust gas turbine and a compressor with an input and an output, an exhaust emissions controller downstream of the exhaust gas turbine, with a first portion of a low pressure EGR loop in fluidic connection with the exhaust emissions controller and the input of the compressor, and a second portion of a low pressure EGR loop in fluidic connection with the output of the compressor and the air inlet of the intake manifold. The dual loop EGR system may further include a first control valve for controlling flow of exhaust through the high pressure EGR loop and a second control valve for controlling flow of exhaust through the first portion of the low pressure EGR loop. In a preferred embodiment, an EGR cooler is disposed along the high pressure EGR loop, and independently an air cooler is disposed along the second portion of the low pressure EGR loop. The dual loop EGR system may further include a control, the control operating the first control valve and the second control valve.

The invention further provides a method for controlling EGR in an internal combustion engine with an exhaust manifold including an exhaust outlet and an intake manifold including an air inlet, the method including providing a high pressure EGR loop with an EGR cooler and a first control valve, the high pressure EGR loop being in fluidic connection with the exhaust outlet of the exhaust manifold and the air inlet of the intake manifold, providing a turbocharger including an exhaust gas turbine with an exhaust emissions controller downstream of the turbine and a compressor with an input and an output, providing a first portion of a low pressure EGR loop with a second control valve in fluidic connection with the exhaust emissions controller and the input of the compressor and a second portion of a low pressure EGR loop in fluidic connection with the output of the compressor and the air inlet of the intake manifold, and controlling the first control valve and the second control valve such that the EGR source is the high pressure EGR loop, the low pressure EGR loop, or a combination thereof. In the method, under low engine load conditions the primary source of EGR is the low pressure EGR loop and under high engine load conditions the primary source of EGR is the high pressure EGR loop. The method can further provide for decreasing condensation within the engine under condensation conditions, such as low ambient air temperature, by

maintaining the low pressure EGR loop as the primary source of EGR at up to moderate engine load conditions.

Other objects, advantages and novel features, and further scope of applicability of the present invention will be set forth in part in the detailed description to follow, taken in conjunction with the accompanying drawings, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The accompanying drawings, which are incorporated into and form a part of the specification, illustrate one or more embodiments of the present invention and, together with the description, serve to explain the principles of the invention. The drawings are only for the purpose of illustrating one or more preferred embodiments of the invention and are not to be construed as limiting the invention. In the drawings:

FIG. 1 is a schematic diagram of an engine and EGR system employing the combination and components of the present invention; and

FIG. 2 is a graph illustrating usage of the dual path EGR system of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, FIG. 1 shows an internal combustion engine system **10** including the dual path EGR system of this invention. Internal combustion engine **12** has at least one cylinder in communication with exhaust manifold **14** and intake manifold **16**. Exhaust manifold **14** is connected to exhaust line **20** which in turn is connected to first control valve **22**, which controls the amount of exhaust gas entering high pressure EGR loop line **24**. Preferably, first control valve **22** can be controlled such that the amount of exhaust gas entering line **24** can range from a pre-determined maximum to no exhaust gas. Exhaust line

24 is connected to EGR cooler **26**, and high pressure EGR loop line **28** connects the outlet of EGR cooler **26** to a first inlet on EGR mixer **30**.

Exhaust gas not diverted to high pressure EGR loop line **24** by first control valve **22** is directed by means of exhaust turbine inlet line **40** to exhaust turbine **44**, which exhaust turbine **44** forms a part of turbocharger **42**. Exhaust gas entering exhaust turbine **44** produces rotational energy, thereby driving compressor **46**. Exhaust gas exits turbine **44** by means of exhaust line **50**, which is connected to emissions controller **52**. Emissions controller **52** includes, in the case of a diesel engine, at least a diesel particulate filter, and optionally further includes one or more of a diesel oxidation catalyst, a lean NOx trap, and a selective catalytic reduction catalyst. Exhaust gas exits emissions controller **52** by means of exhaust line **54**, which interconnects with and is in fluidic connection with exhaust gas compressor inlet line **60**. Exhaust gas not diverted to exhaust gas compressor inlet line **60** is permitted to exit the engine system **10** by means of exhaust **56**.

Exhaust gas diverted to exhaust gas compressor inlet line **60** is controlled by second control valve **62** disposed along line **60**. Second control valve **62** controls the amount of exhaust gas diverted from the exhaust, with the diversion at a point downstream of emissions controller **52**. As with first control valve **22**, preferably second control valve **62** can be controlled such that the amount of exhaust gas passing through second control valve **62** can range from a pre-determined maximum to no exhaust gas. Second control valve **62** is connected, on the outlet side, to exhaust gas compressor inlet line **64**, which interconnects with and is in fluidic connection with compressor air inlet line **68**. Air inlet line **68** is connected to a source of fresh air by means of inlet **66**, it being understood that inlet **66** may further comprise air filters and similar structures. Fresh air enters compressor **46**, driven by turbine **44**, together with the amount of exhaust gas introduced through exhaust gas compressor inlet line **64**, it being understood that quantity of exhaust gas is controlled by second control valve **62**. In practice, the amount of exhaust gas, as a percentage of total intake to compressor **46**, can range from 0% to about 50%. When the low pressure EGR loop is the sole or primary source of intake gas to intake manifold **16**, the amount of exhaust gas, as a percentage of total intake to compressor **46**, can range from about 5% to about 50%.

Compressor **46** compresses the mixture of fresh air and exhaust gas entering by means of air inlet line **68**, with the compressed gas exiting compressor **46** by means of an intake manifold conduit, low pressure EGR loop line **70**. Line **70** is in turn in fluidic connection with air cooler **72**, optionally provided, with the gas exiting air cooler **72** by means of low pressure EGR loop line **74**. Line **74** is connected to a second inlet on EGR mixer **30**. EGR mixer **30** permits the gas entering by means of line **74** and line **28** to be mixed prior to entry into the engine by means of inlet line **32**, connected to the outlet of EGR mixer **30** and to an inlet port of intake manifold **16**. EGR mixer **30** further optionally comprises a proportioning gas control valve, to mix controlled proportions of the combined compressed air and exhaust gas from low pressure EGR loop line **70** with exhaust gas from high pressure EGR loop line **28**, or, if second control valve **62** is closed, to mix controlled proportions of compressed air from line **70** with exhaust gas from high pressure EGR loop line **28**.

Turbocharger **42** is optionally and preferably a variable geometry turbocharger, most preferably the variable geometry turbocharger as disclosed in commonly owned United States Patent No. 6,269,642, issued August 7, 2001, and incorporated herein by reference. The preferred variable geometry turbocharger permits the vanes of turbine to be actuated by a hydraulic actuator, such that the efficiency or operational range of the turbine **44** can be varied during operation, thereby providing for optimal system efficiency, particularly when the low pressure EGR loop is delivering compressed exhaust gas to intake manifold **16**. It is to be understood that the invention is not limited to the variable geometry turbocharger of Patent No. 6,269,642, and that other variable geometry turbochargers may be employed, and further that turbochargers not providing for variable geometry may be employed. However, a variable geometry turbocharger provides for increased system efficiencies and control of mass throughput not readily obtainable with standard turbochargers.

Where a variable geometry turbocharger is employed, optionally and preferably a variable geometry turbocharger control system is employed, most preferably the variable geometry turbocharger control system as disclosed in commonly owned United States Patent Application No. 2003/0145591, published August 7, 2003, and incorporated herein by reference. Such a system can employ a variety of methods for optimizing efficiency of the

turbocharger. Thus, for example, a conventional proportional integral differential technique can be employed to position an actuated vane, based on an error value, err_{boost}, calculated as the difference between a boost target determined from a boost target map and the actual boost. Alternatively, the desired actuated vane position may be determined by related methods, utilizing proportional integral differential techniques or modifications thereof, based on parameters relating to the vane position, proportional gain values, differential gain values, err_{boost} values, turbo speeds, turbo speed targets, engine modes (idle, power or braking), and the like, as taught in Application No. 2003/0145591.

Control valves **22** and **62** may incorporate aspects of the control valve disclosed in commonly owned United States Patent No. 5,937,650, issued August 17, 1999, incorporated herein by reference, and thus may incorporate a proportional electrical solenoid that acts on a three-way pneumatic or hydraulic valve with opposing force provided by a differential pressure generated by the flow through a separate exhaust gas recirculation valve. A control valve as disclosed in Patent No. 5,937,650 is specially adapted for EGR control. In a preferred embodiment, control valves **22** and **62** are adapted for control by electrical means, such as by means of output signals from a microprocessor-based system. However, any of various electrical, mechanical or electromechanical control mechanisms can be used to control the valves. The valves are preferably controlled in response to one or more operating parameters of the engine **12** or engine system **10**, in response to predetermined conditions or settings, or in response to operator provided instructions.

In a preferred embodiment, the internal combustion engine system **10** includes an engine control unit (ECU) (not shown). The ECU is in connection with one or more sensors (not shown) that monitor one or more operating parameters of engine **12** or engine system **10**. Relevant operating parameters include, without limitation, the quantity of fuel flow to engine **12**, the engine speed of engine **12**, air flow at one or more points within engine system **10**, turbine **44** speeds, compressor **46** pressure ratios, engine **12** operating temperatures at one or more locations, ambient environment or air temperatures and the like. The operating parameters sensed by the ECU are determined, in part, by the specific requirements of the ECU, and by data required for determining one or more output signals. It

is to be understood and appreciated that less than all of the foregoing operating parameters may be utilized, and that in addition to the foregoing specified operating parameters, one or more additional operating parameters may be utilized. In a preferred embodiment, the ECU includes a microprocessor configured to receive signals from the sensors measuring engine system **10** or engine **12** operating parameters, and to perform one or more processes or calculations thereon, which processes or calculations may include comparison to maps or data stored in a memory component of the ECU. Based on one or more processes or calculations, or by comparison to predetermined conditions, the ECU can then provide an output signal, which output signal can control one or more of control valve **22**, control valve **62**, actuatable vanes or other components within turbocharger **42** where turbocharger **42** is a variable geometry turbocharger, and a proportioning gas control valve, if provided, of EGR mixer **30**. In a preferred embodiment, the ECU provides an output signal to control both control valve **22** and control valve **62**, more preferably to additionally control an operational component of turbocharger **42** where turbocharger **42** is a variable geometry turbocharger, and most preferably to further and additionally control a proportioning gas control valve of EGR mixer **30**. It is to be understood and appreciated that the foregoing are the primary operating parameters and controls relating to the system and method for dual path EGR, as disclosed herein, utilizing a high pressure EGR loop and a low pressure EGR loop, and that the ECU may accept operating parameters, and may provide controls, for functions other than operation of the EGR system.

In operation, the ECU monitors operating parameters of engine **12** or engine system **10**, and in response to detected parameters, provides one or more output signals to control valve **22** and control valve **62**, and optionally to actuatable vanes or other components within turbocharger **42** wherein turbocharger **42** is a variable geometry turbocharger, and further optionally to a proportioning gas control valve, if provided, of EGR mixer **30**. The engine **10** is preferably started with first control valve **22** positioned such that no exhaust gas enters high pressure EGR loop line **24**. Second control valve **62** is in an open or partially opened position, such that exhaust gas, when generated, enters air compressor **46** by means of exhaust gas compressor inlet line **64**. It is to be understood that while the foregoing is a

preferred method of starting the engine, so as to minimize NOx emissions and maximize fuel economy, alternatives configurations may be employed in starting the engine. In low load operations, such as a truck diesel engine at an idle, it is preferable to continue operating engine **12** with first control valve **22** positioned such that no exhaust gas enters high pressure EGR loop line **24**, and second control valve **62** is in an open or partially opened position, such that exhaust gas enters air compressor **46** by means of exhaust gas compressor inlet line **64**. Under low load operations, generally very high EGR rates are required. The negative Δp required to drive the EGR if a high pressure EGR loop were employed would result in a substantial fuel economy penalty. Use of the low pressure EGR loop minimizes the fuel economy penalty, and further allows very high EGR rates to be achieved. During moderate to high load operations, it is preferable to operate engine **12** with first control valve **22** positioned such that exhaust gas enters high pressure EGR loop line **24**, transits EGR cooler **26**, and enters intake manifold **16** by means of EGR mixer **30**. Second control valve **62** is in a closed or partially closed position, such that little or no exhaust gas enters air compressor **46** by means of exhaust gas compressor inlet line **64**. Thus under moderate or high load operations the high pressure EGR loop is utilized, which provides the best fuel economy and minimizes the boost pressure and heat load on the vehicle cooling system.

It may readily be seen that the system may operate in a binary fashion, such that EGR is provided by either the high pressure EGR loop or the low pressure EGR loop, or may be operated in a combination fashion, such that EGR is provided by both the high pressure EGR loop and the low pressure EGR loop. In one embodiment, the ECU is programmed such that there is a transition range between operation of the high pressure EGR loop and the low pressure EGR loop; for example, when transitioning from low load to moderate or high load conditions, second control valve **62** may be gradually closed, over some ascertained range or operating parameters, and first control valve **22** is gradually opened so as to allow increasing quantities of exhaust gas to enter high pressure EGR loop line **24**.

Given that the low pressure EGR loop is only used during low load operations, an EGR cooler is not required for the low pressure EGR loop. Further, exhaust gas particulates

and other noxious compounds that might impede the efficient and continued operation of compressor **46** are removed by emissions controller **52**.

Under certain ambient environmental conditions, such as low temperature, condensation of EGR results from use of a high pressure EGR loop, and specifically primarily as a result of use of an EGR cooler, such as EGR cooler **26**. The low pressure EGR loop of the present invention does not require or provide an EGR cooler, and accordingly there will be no or significantly reduced condensation in the low pressure EGR loop. Thus by using the low pressure EGR loop, substantially less water, with its resulting deleterious results, will enter intake manifold **16**, as compared to the quantity of water that would enter under low temperature conditions utilizing the high pressure EGR loop and EGR cooler **26**. It may thus be seen that the switching point between the low pressure EGR loop and the high pressure EGR loop may be adjusted, for example by delaying initiation of the high pressure EGR loop, under certain ambient environmental conditions, such as low temperature, until such power is generated that the exhaust is of sufficient temperature as to not be cooled below the dew point within the EGR cooler. In this embodiment, a desired operating parameter to be detected by the ECU includes ambient environment or air temperature, and one or more temperature sensors, including one or more sensors measuring air temperature at inlet **66**, may be provided for this purpose.

FIG. 2 graphically depicts engine operating conditions under which the low pressure EGR loop or the high pressure EGR loop may be selected, such as for example by the ECU. FIG. 2 depicts torque, representing load, versus engine speed. It may be seen that with low torque conditions at all engine speeds the low pressure EGR loop is preferred. However, as the torque increases the "switching point" line is reached, wherein the high pressure EGR loop is preferred. In general, as the engine speed increases, the amount of torque required to preferably switch to the high pressure EGR loop is decreased. It may also be seen that under certain environmental conditions, such as condensation conditions, the preferred switching point at all speed settings is increased, such that switching to the high pressure EGR loop is delayed. Thus in FIG. 2 the dashed line represents a preferred switching point line when the engine is operated under condensation conditions, such as resulting from low

ambient air temperatures. It may readily be seen that the parameters depicted on FIG. 2, such as torque and engine speed, may be detected by any of a variety of sensors, and that an ECU may be employed to determine the appropriate switching point under any given operating parameters.

Although the invention has been described in detail with particular reference to these preferred embodiments, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and it is intended to cover in the appended claims all such modifications and equivalents. The entire disclosures of all references, applications, patents, and publications cited above are hereby incorporated by reference.